Basic Research Needs Workshop on Compact Accelerators for Security & Medicine May 6-8, 2019: *Preliminary Findings*

Workshop Chair: Michael Fazio (SLAC National Accelerator Laboratory)

Security Co- Chair: Suresh Pillai (Texas A&M and Director of the National Center for Electron Beam Research)

Medicine Co- Chair: George Laramore (Univ. of Washington)

DOE/SC Technical Lead: Eric Colby (HEP)

Federal Coordinating Group: Eliane Lessner, **DOE-BES**, Kramer Akli, **DOE-FES**, L.K. Len, **DOE-HEP**, Manouchehr Farkhondeh, **DOE-NP**, Jeff Buchsbaum, **NIH-NCI**, Namdoo Moon, **DHS-CWMD**, Keith Jankowski, **DHS-CWMD**, Lance Garrison, **DOE-NA21**, Donny Hornback, **DOE-NA22**, Fredrik Tovesson, **DOE-NA22**, Quentin Saulter, **DOD-ONR**, Mark Wrobel, **DOD-DARPA**.

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NNSA

NIH

High-impact Investment in Accelerator Technology for Security & Medicine Requires a Clear View of a Broad Set of Issues

Technology Applicability and Readiness

- Transformative, not incremental research directions
- Both accelerator technology and application-side technology (Including Detector Technology)
- TRL = 4* in 5 years

Regulatory Acceptance

Existing and anticipated

Existing Market Conditions

Economics, industry providers, IP whitespace, conservatism

Pathways to commercial products

First adopters and eventual markets

* Technical Readiness level (TRL) = 4: Component and/or breadboard validation in the laboratory environment

BRN for Compact* Accelerators – Workshop Motivation

- *Bridging the gap between accelerator research and technology deployment*
- The landscape has evolved considerably
  - Many accelerator technology advances of the last 1-2 decades have not been fully adopted in the field
  - New applications have emerged
  - New technology slow to be incorporated into accelerators and their applications
- Want to understand the highest impact applications enabled by both prior advances and current R&D efforts, and develop a list of Priority Research Directions (PRDs) for the future that produce transformative advances.
- Charge for this Basic Research Needs (BRN) workshop was developed in consultation among the four sponsoring federal agencies

* "Compact" depends on the application, and can range from millimeters to a few meters.

Basic Research Needs for Compact Accelerators– Charge

1. **Assess the state of existing accelerator and non-accelerator based technology** currently deployed. **Document cost and performance criteria**
2. **Document current and proposed** Federal and State ES&H **regulatory requirements** & issues
3. **Develop performance criteria** for the applications, total system costs for production and operation. **Assess the potential** financial and/or application benefits if meet the criteria. **Document specifications** for the accelerator and detector components.
4. **Identify technical gaps** between the current state of the art of accelerator technology compared to the above specifications.
5. **Identify synergistic application-side R&D**
6. **Specify R&D activities needed to bridge technical gaps**
7. **Develop a prioritized list of R&D**; estimate ROM costs for R&D.

Outcome: Report with high-impact applications, **PRDs,** and R&D roadmaps

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Question 4 (highlighted) is what technical people think is most important, but no business case exists without the other 6 questions

Workshop Organizing Committee Consisted of 7 Working Groups

- **Michael Fazio** – Workshop Chair
  - **Suresh Pillai** – Co-Chair for Security
    - **Harry Martz** – WG Co-Lead
    - **Ahmed Badruzzaman** – WG Co-Lead
  - **George Laramore** – Co-Chair for Medicine
    - **Jeff Buchsbaum** – WG Co-Lead
    - **David Jaffray** – WG Co-Lead
    - **Keara Boss** – WG Co-Lead
  - Technology Cross-Cut Working Groups
    - Materials & Sources
      - **Andrea Schmidt** – WG Co-Lead
      - **Jeff Calame** – WG Co-Lead
    - Computer Design & Control
      - **Sandra Biedron** – WG Co-Lead – Design
      - **John Cary** – WG Co-Lead – Controls
    - Engineering
      - **Mark Curtin** – WG Co-Lead – Cost-Reduction
      - **Arlyn Antolak** – WG Co-Lead – Ruggedization
    - Detectors
      - **Anna Erickson** – WG Co-Lead – Security
      - **Ron Tosh** – WG Co-Lead – Medicine
    - Future Accelerator Concepts
      - **George Neil** – WG Co-Lead – Supercon-ducting RF
      - **Tony Ting** – WG Co-Lead – Adv. Accel. Concepts

Working Group Panel Definitions

Applications Working Groups = "Systems-level" perspective

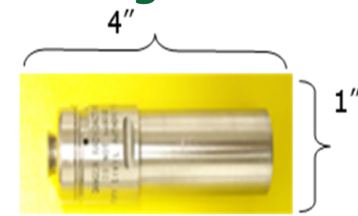
- **Security** – Accelerator-based Security Applications
- **Medicine** – Accelerator-based Medical Applications

Technology Cross-Cut WGs = "Technology" perspective

- **Materials & Sources** – Looks at R&D needed to achieve the accelerator beam performance specifications set out by the Applications WGs.
- **Computer Design & Control** – Looks at the advances in computer hardware and software R&D needed to (1) accurately simulate performance for design purposes, and (2) provide robust highly-automated accelerator control.
- **Engineering** – Looks at the engineering advances and R&D needed to (1) reduce cost, (2) provide rugged fixed & portable accelerator systems.
- **Detectors** – Looks at the detector R&D needed to achieve the application sensitivity requirements set out by the Applications WGs.
- **Future Accelerator Concepts** – Looks at longer-term R&D needed for superconducting RF and advanced accelerator concepts to meet performance specifications set out by the Application WGs.

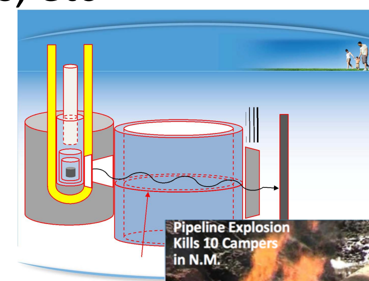
Motivation: Security Applications

Accelerators can provide non-isotopic, and thus less risky, sources of ionizing radiation

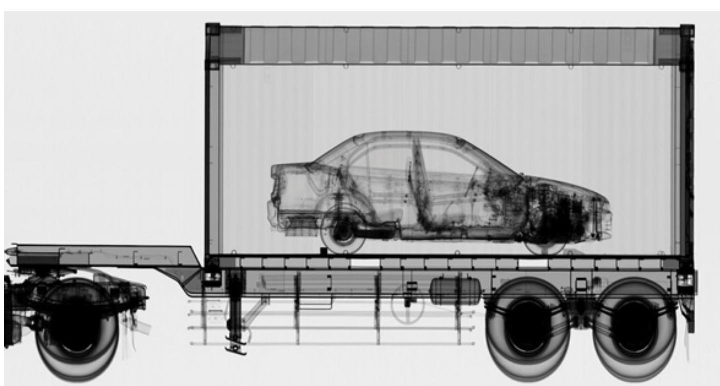


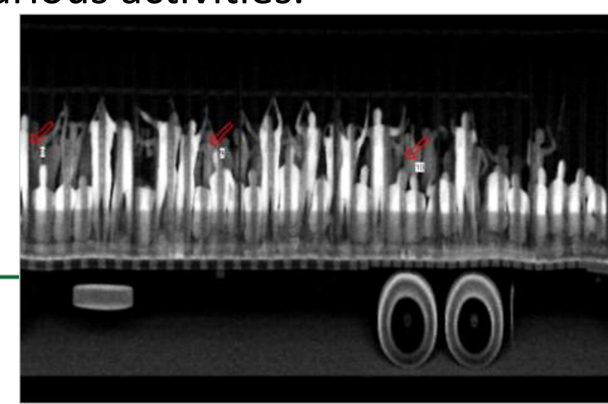
Cs-137 Capsule

- Non-invasive probing
  - ➢ interrogation of geological media
  - ➢ radiography for non-destructive testing & evaluation of structures,
  - ➢ probing of cargo for contrabands such as narcotics, SNM, munitions, etc
- Industrial radiation processing
  - medical device sterilization & pharmaceuticals,
  - food processing (for safety and quality)
  - Phytosanitary & sterile insect technology



All of these applications are largely reliant on radioisotopes, thereby posing security risks from the possibility of these sources being diverted for nefarious activities.





Accelerators/beams Enhance Food Quality & Safety

Farm to Flour – A Dreadful Journey…

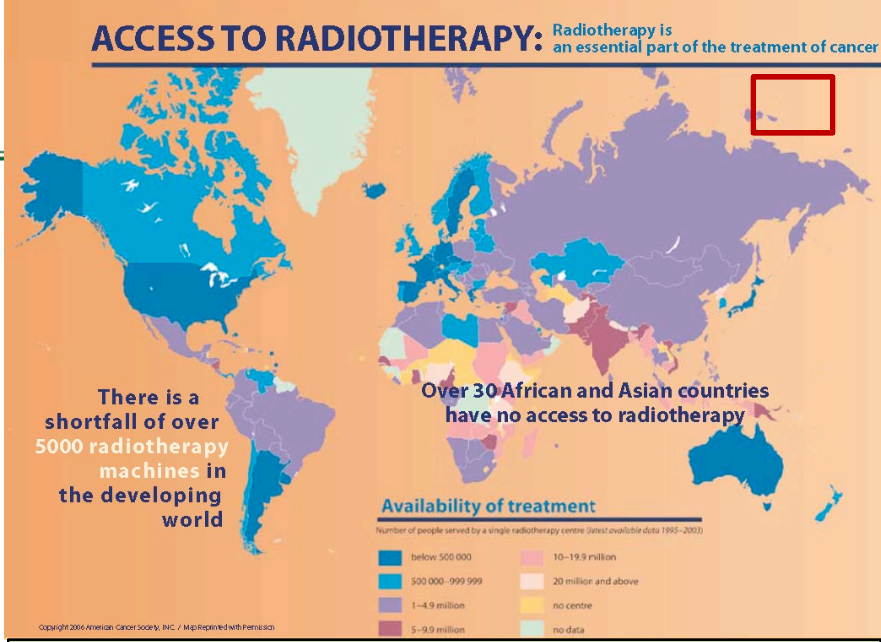
No validated kill step!

As fresh as you can get!!!
Neither washed nor disinfected!

New trends and challenges!

Shima Shayanfar | General Mills Inc.

Motivation: Medicine Applications



Three parallel agendas for the medical application space

- New technologies allowing complexity of radiation therapy to be hidden from the user for greater access and quality globally
  - Lack of medical physicists
  - Power outages
- New technologies for robust systems (i.e. low cost and with very high reliability)
- New technologies to explore the power of radiation in biology (e.g. radiation allowed us to discover cancer stem cell paradigm, and there are new emerging frontiers- e.g. flash RT)

Global Incidence of cancer cases grows from 14M to 25M per year between 2012 and 2030.

Animal experience before human applications

Tumor between eyes - great test for Intensity modulated RT-
CT and treatment

Applications areas needing innovative solutions chosen as the *Focus of the Workshop*

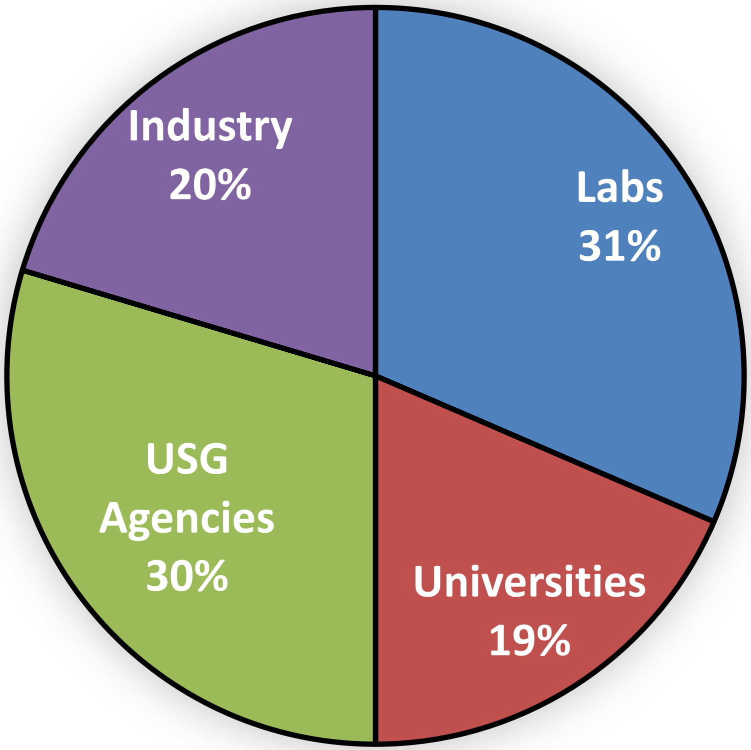
- **Replacement of radioisotopic sources by accelerator-based alternatives**
- **Ruggedized low-cost linacs for Low/Middle-Income Countries**
- **FLASH-RT and Very-high energy electron (VHEE) sources for radiotherapy**
- **Source-free brachytherapy (i.e. endoscopic particle accelerators)**
- **Portable monochromatic gamma-ray sources, and**
- **Compact neutron generators.**

Many of these are applicable to both security and medicine

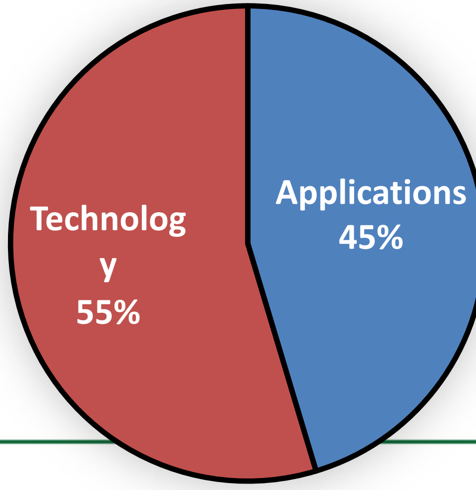
New application areas (not listed above) may be added as "Emerging Applications" at the discretion of the workshop chairs
e.g. LMIC & usable preclinical machines

Attendees Spanned a Broad Swath of Labs, Universities, Industry, and USG Agencies

Total attendees = 112



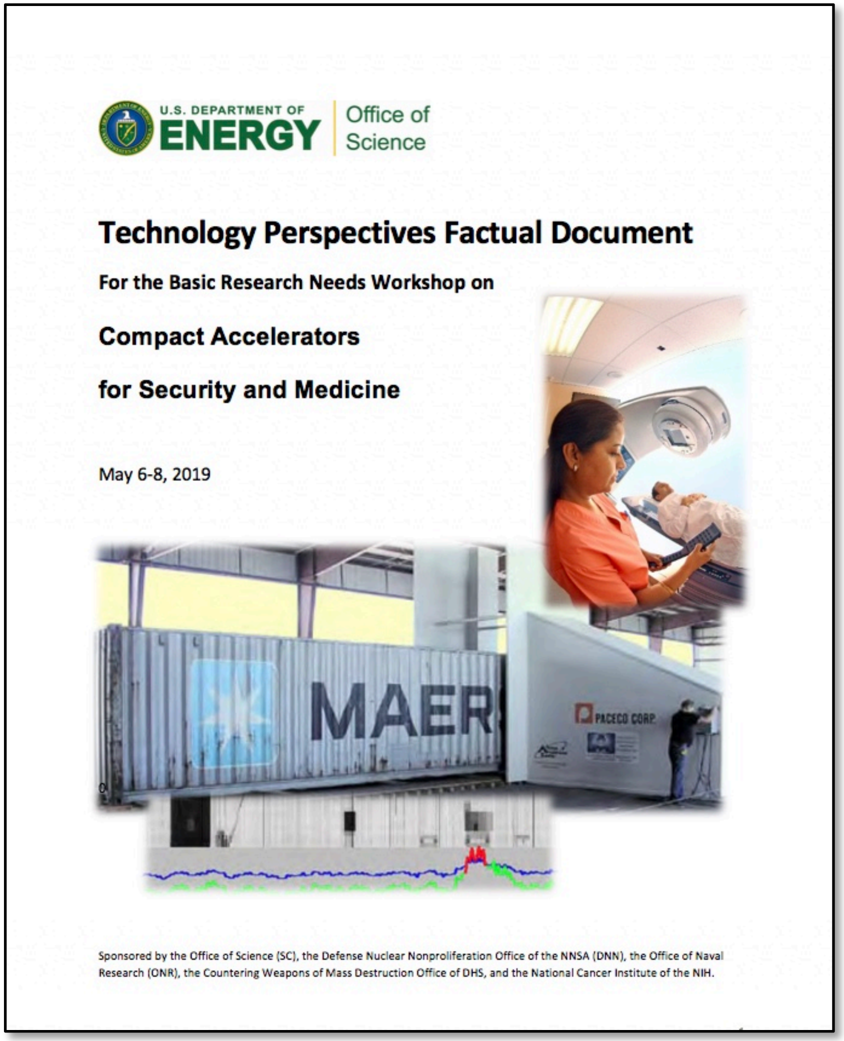
- Labs (34)
- Universities (20)
- USG Agencies (32)
- Industry (22)
- Medicine (22)
- Security (17)
- Technology (47)



Chair & Co-chairs	3
WG co-leads	15
Panelists	~ 45
Observers	~ 18
Federal Observers	~ 26
Plenary speakers	7

Technology Perspectives Factual Document (TPFD) formulated prior to Workshop to Frame the Discussion

- Provides all attendees a common understanding of challenges and questions (no tutorials at Workshop)
- Created by Co-chairs & Working Group Co-leaders with input from others
- 100 pages addressing both application areas ands each of 5 technology areas
- Released 11 days prior to Workshop
- TPFD covers existing technology state-of-the-art (cost & performance), performance criteria for envisioned applications, assessment of benefit if achieved.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Technology Perspectives Factual Document

For the Basic Research Needs Workshop on

Compact Accelerators

for Security and Medicine

May 6-8, 2019

Sponsored by the Office of Science (SC), the Defense Nuclear Nonproliferation Office of the NNSA (DNN), the Office of Naval Research (ONR), the Countering Weapons of Mass Destruction Office of DHS, and the National Cancer Institute of the NIH.

Plenary Talks Defined the Needs & Challenges in Security and Medicine Applications

- *Enabling Next-Generation Techniques in Cancer Treatment*

  C. Norman Coleman, M.D. NCI
- *Improving Healthcare in Low- and Middle-Income Countries*

  Eric Ford, PhD FAAPM Professor University of Washington
- *Advancing External Beam Radiotherapy*

  James S. Welsh MS, MD Loyola University Stritch School of Medicine
- *Seeing the Unseen--Nondestructive Evaluation*

  Ahmed Badruzzaman, ANS Fellow Pacific Consultants & Engineers
- *R&D Perspectives on Ensuring the efficacy of the National Stockpile*

  David J. Funk, Los Alamos National Laboratory, DOE/NNSA
- *Securing the Food Supply without the Radiological Security Risk*

  Shima Shayanfar, Product Stability Scientist, General Mills Inc.
- *R&D Perspectives on Cargo Scanning*

  Richard J. Vojtech, Countering Weapons of Mass Destruction Office, DHS

Workshop Temporal Structure (3 days, ~36 hours)

8:00 am to 10:00 pm

	Day 1	Day 2	Day 3
Morning	Security & Medicine Plenaries	*Refine Applications PRDs, Panel Summaries, Outbriefs* Security Working Group / Medicine Working Group	Applications & Technology X-cut Working Groups PRD Reports
Afternoon	*Develop requirements* Security Working Group / Medicine Working Group	*Examine requirements & gather input* Technology Cross-cut Working Groups	Begin report writing and PRD distillation
Evening	*Draft PRDs* Security Working Group / Medicine Working Group	*Develop PRDs & Panel Summaries* Technology Cross-cut Working Groups	

Target date for Brochure and BRN Workshop Report: mid-summer 2019

What is a Priority Research Direction?

- It is a high-level S&T objective that will guide R&D for 5-10 years or more
- Transformative, changes the game, renders the impossible possible
- Informs the scientific community, application community, and lawmakers about the process and findings of the workshop
- Workshop produced 38 pre-PRDs (research themes) distilled to 5 PRDs

(Draft) PRD 1: Hardware Focused System Co-design

Create a new paradigm for accelerator systems through end-to-end accelerator co-design to produce modular, interoperable, easy-to-use, integrated, reliable, hardware solutions

- **Key Ideas**
  - Continuum of complexity management: hardware focus
  - Component modularity, rapid interchangeability, strong commercial ecosystem leads to *best of class systems*
  - Engineering standards promote
    - Interoperable products
    - Reduce costs
    - Increase reliability

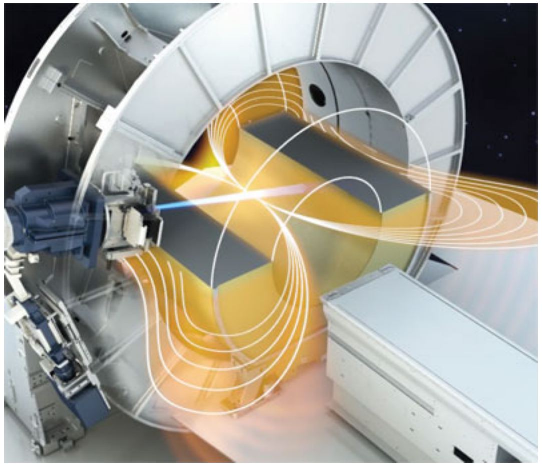
In-house eBeam for aseptic packaging- Shima General Mills

- **Key Questions**
  - When to co-design, and when to component optimize?
  - Can engineering standards increase reliability and interoperability?
  - Can system design facilitate autonomous dose delivery?

(Draft) PRD 2: Smart Systems

Develop "Smart" Accelerators that require minimal technical expertise to produce expert results in any human-resource environment, with software robustness and fault-tolerance

- **Key Ideas**
  - Continuum of complexity management:
    software focus
  - Smart control systems
    - Self-diagnose
    - Self-repair
    - Self-adjust
    - ➡ Autonomous operation
  - AI/ML-based system control and data management systems



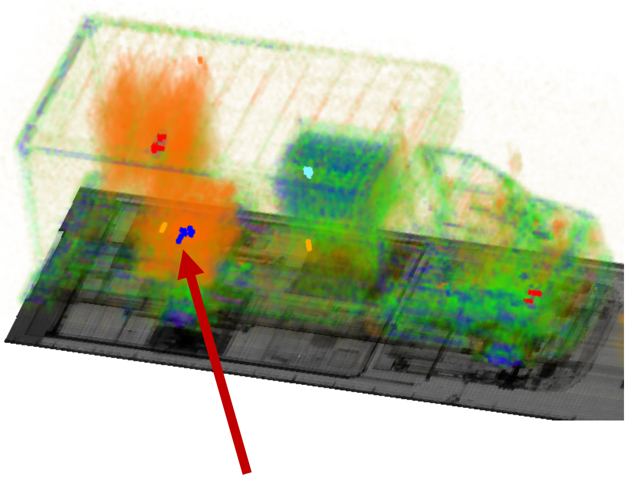
MRI-linac, integrated treatment-imaging concept (Welsh)

- **Key Questions**
  - Can ML enabled systems provide:
    - self-diagnosis?
    - best outcomes?
    - dose optimization
  - How "autonomous" can accelerator-based systems be made?
  - Can AI-based cybersecurity protect
    - Accelerator control?
    - Data system?
  - Can engineering standards ensure interoperability of multi-vendor systems?

(Draft) PRD 3: See Beyond Current Technological Limits

See beyond current technological limits with systems that provide more flux, controlled bandwidth, and improved detection for more accurate measurements and reduced collateral effects

- **Key Ideas**
  - System R&D focus on the target properties
  - Real-time imaging data-based system optimization
    - Image analysis-based target motion correction
  - Advanced detector technologies with expanded sensitivity, capability, ruggedness



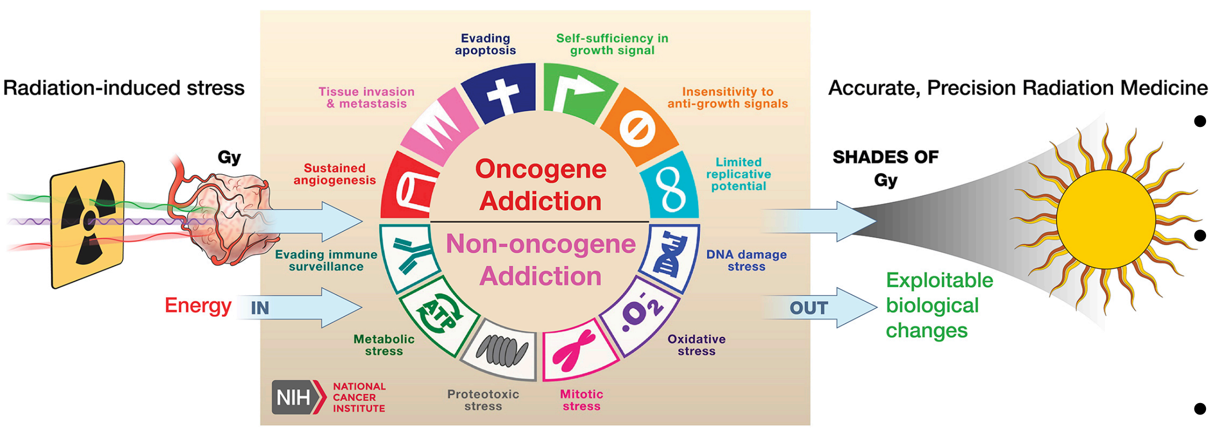
Do we know enough to make a decision?

- **Key Questions**
  - Is better imaging possible by closely integrating sources and detectors?
  - How can detection algorithms be improved?
  - Can monochromatic, coherent, and tunable x-ray sources be developed?
  - How can spectrum, bandwidth, and coherence be controlled?
    - Benefits?
  - Can more accurate CT imaging simulations be developed?

(Draft) PRD 4: Control Outcomes Beyond Current Limits

Control effects and outcomes beyond current technological limits with systems that provide more flux and better control of stability, spectrum, and dose for substantially improved capability and impact

- **Key Ideas**
  - Contextually optimize dose – spatial & temoral in real time
  - Expand source/detector capability to enable new translational and clinical science, e.g. flash/VHEE
  - System R&D focus on the target properties



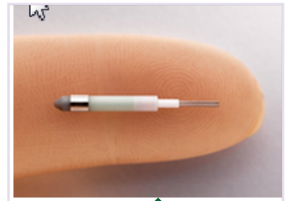
Better cancer care, Better treatment outcomes

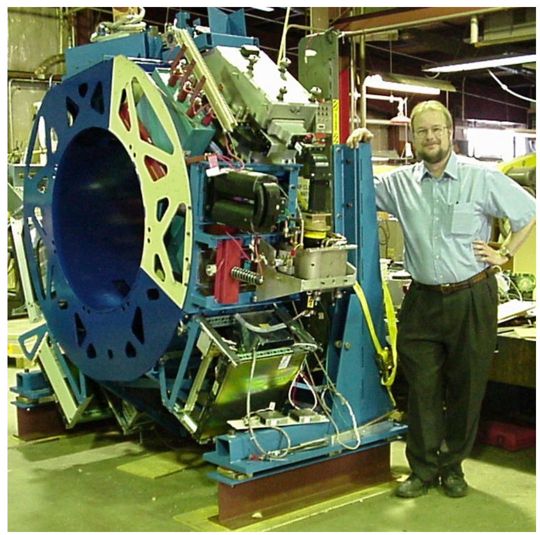
- **Key Questions**
  - Can higher capability source/detectors improve outcomes?
    - Increase flux/efficiency?
    - Reduce cost?
  - Can energy spectrum and dose rate be optimized to reduce collateral damage?
  - How to maintain accuracy at high dose rate?
  - What advancements are needed for ultrahigh dose rate in a clinical setting?
  - What radiobiology must be studied?

(Draft) PRD 5: Revolutionize Size (aka Size Matters)

Revolutionize the size, making accelerators smaller to enable new and emerging applications, reducing cost and risk

- **Key Ideas**
  - Increase accelerator gradient and power efficiency
  - Increase system power efficiency ("wall plug" to delivered beam)
  - Advanced manufacturing and new materials
  - Convert mechanical components to
    - organic/chemical /biologic, or field based "components"





Prototype of TomoTherapy machine (x-ray and CT) and Xoft endoscopic x-ray source (50 keV)

- **Key Questions**
  - What are the key SWaP drivers for the application?
  - Can accelerators be miniaturized for:
    - tight crawl spaces?
    - Pipes?
    - Boreholes?
    - Endoscope?
  - Can accelerators be developed for hostile environments?

Summary

- Bridging the gap between accelerator research & technology deployment
- Technology Perspectives Factual Document (TPFD) formulated prior to Workshop to Frame the Discussion
- Vigorous discussion and exchange of ideas among a very diverse set of participants
- Intense 3 days with long hours
- PRDs are in the process of refinement
- Report writing underway
- Workshop Report to be completed by mid-August